Crop response to nitrogen-phosphorus colimitation: theory, experimental evidences, mechanisms, and models. A review

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Harpole et al. (2011) (Fig 3). The independent super- and sub-additive colimitation (contrasting) stands for field trials characterized by a super-additive colimitation at low N and P inputs and a sub-additive colimitation at high N and P inputs.

Fig. 7: Schematic representation of mechanisms involved in N and P acquisition and NxP interactions in the soil–plant system of a crop. Nitrogen fixation and all related processes are a specificity of legume crops, while other mechanisms are common to most crops. The representation focus on trade-off and effect between nutrient (C,N,P). Blue arrows stand for Carbon (C) effect (dashed) and allocation (plain), green for Nitrogen (N) and orange for Phosphorus (P). Pools of the three nutrient are represented through plain boxes. Processes and organs that are involved in N and P acquisition are also represented respectively with rounded dashed boxes and simple dashed boxes. H^+ and OH^- stands respectively for proton and hydroxyl and APase stands for Acid Phosphatase.

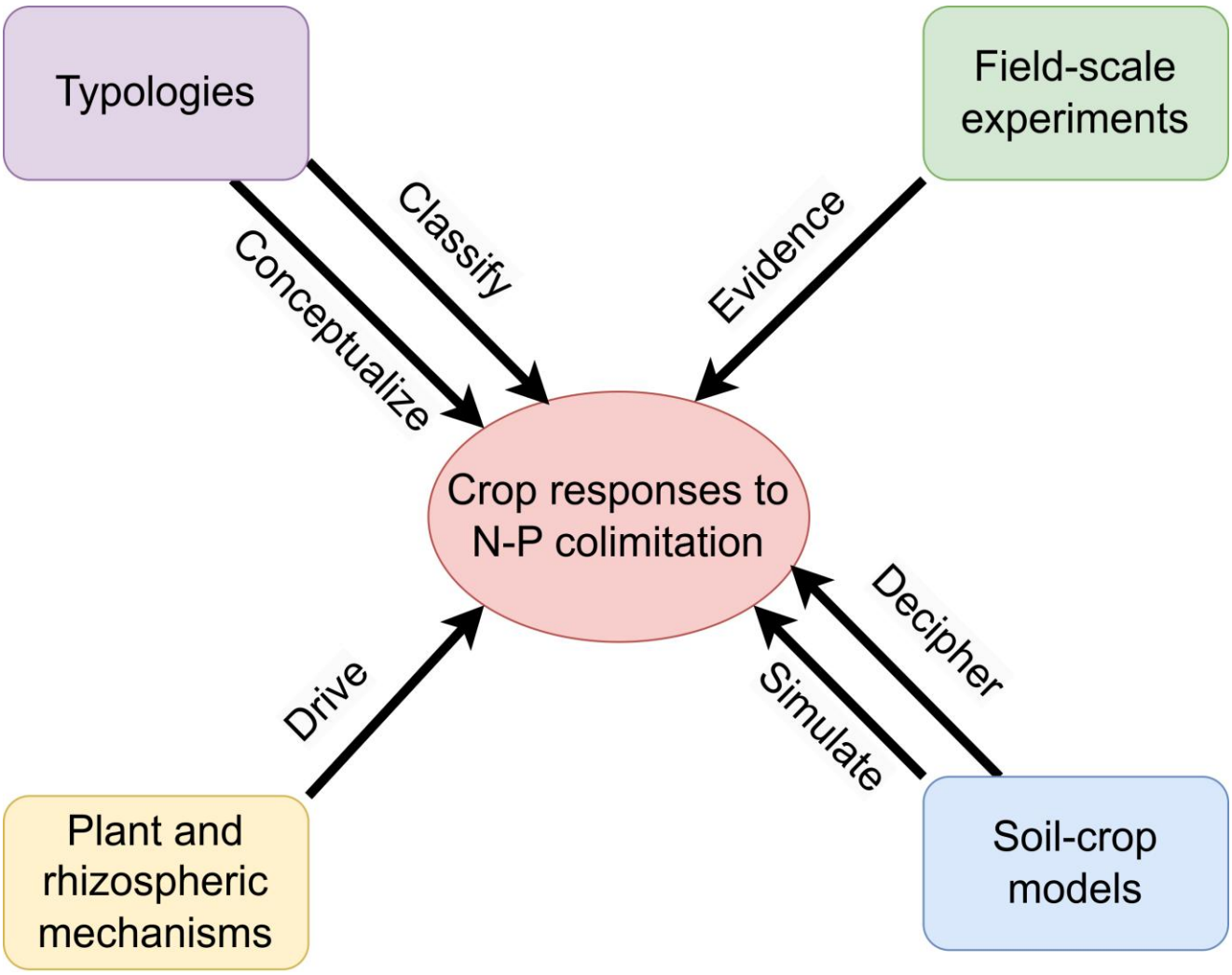

Typologies
Field-scale experiments
Classify
Conceptualize
Evidence
Crop responses to N-P colimitation
Drive
Simulate
Decipher
Plant and rhizospheric mechanisms
Soil-crop models

Fig. 1.

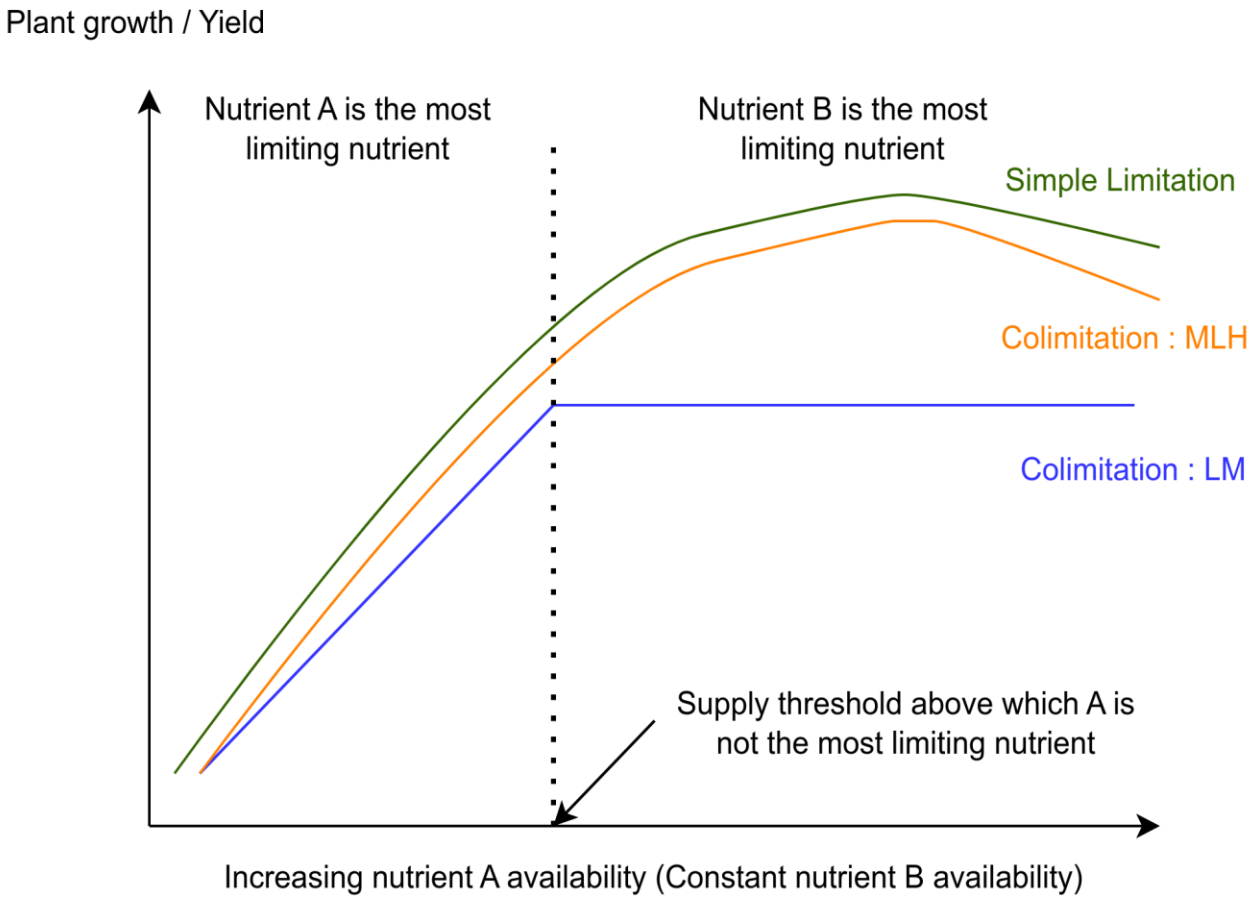

Plant growth / Yield
Nutrient A is the most limiting nutrient
Nutrient B is the most limiting nutrient
Simple Limitation
Colimitation : MLH
Colimitation : LM
Supply threshold above which A is not the most limiting nutrient
Increasing nutrient A availability (Constant nutrient B availability)

Fig. 2

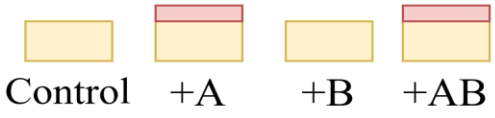
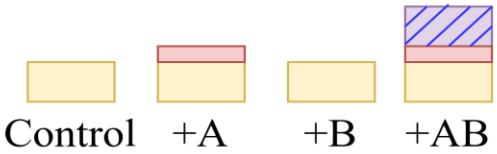
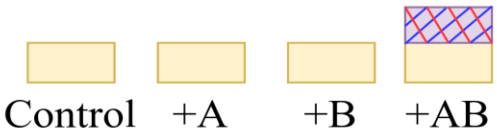
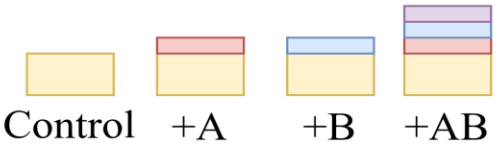
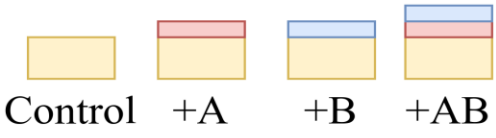
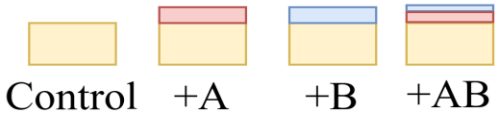
Type of limitation	Crop response
(a) Simple limitation (Only A is limiting)	(a) 
(b) Serial limitation (Most limiting nutrient = A)	(b) 
(c) Simultaneous colimitation	(c) 
(d) Independent colimitation	(d.1) Super-Additive 
	(d.2) Additive 
	(d.3) Sub-Additive 

Fig. 3.

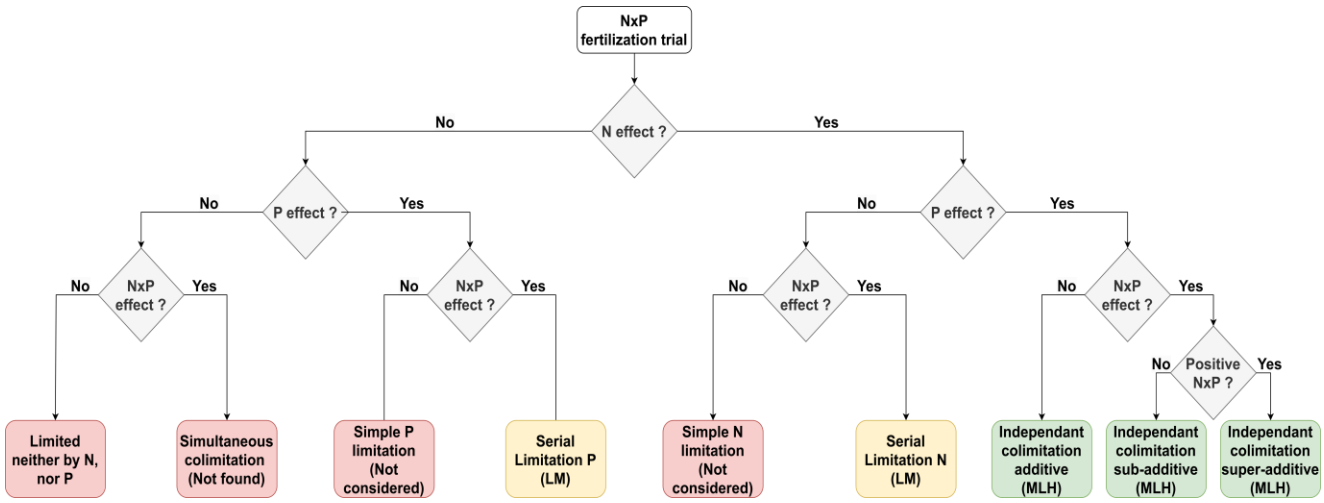

NxP fertilization trial
N effect ?
No
Yes
P effect ?
No
Yes
P effect ?
No
Yes
NxP effect ?
No
Yes
NxP effect ?
No
Yes
NxP effect ?
No
Yes
NxP effect ?
No
Yes
Positive NxP ?
No
Yes
Limited neither by N, nor P
Simultaneous colimitation (Not found)
Simple P limitation (Not considered)
Serial Limitation P (LM)
Simple N limitation (Not considered)
Serial Limitation N (LM)
Independant colimitation additive (MLH)
Independant colimitation sub-additive (MLH)
Independant colimitation super-additive (MLH)

Fig. 4

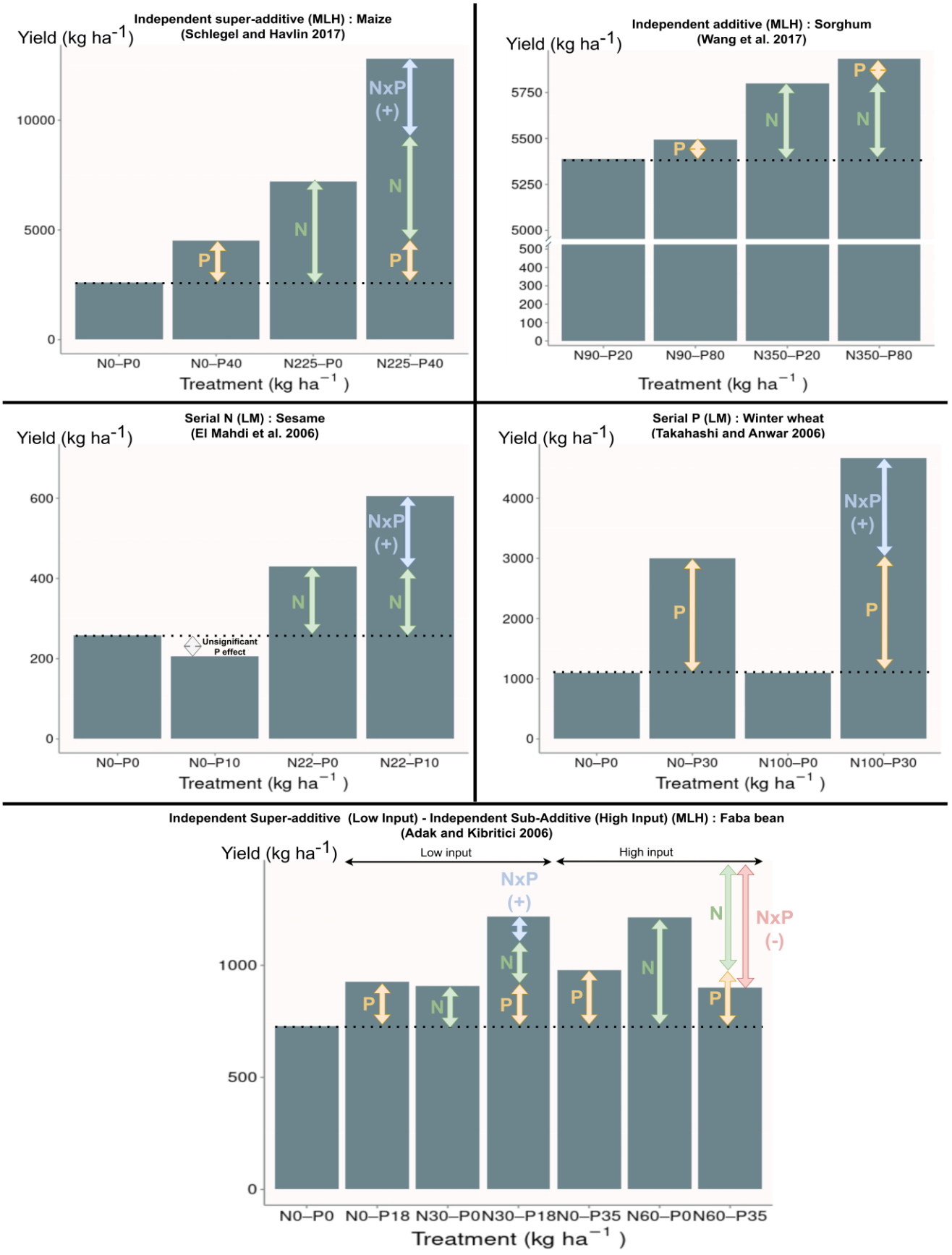

Independent super-additive (MLH) : Maize
(Schlegel and Havlin 2017)
Yield (kg ha-1)
10000
5000
0
NxP
(+)
N
P
N
P
N0–P0
N0–P40
N225–P0
N225–P40
Treatment (kg ha−1)
Independent additive (MLH) : Sorghum
(Wang et al. 2017)
Yield (kg ha-1)
5750
5500
5250
5000
500
400
300
200
100
0
P
P
N
N
N90–P20
N90–P80
N350–P20
N350–P80
Treatment (kg ha−1)
Serial N (LM) : Sesame
(El Mahdi et al. 2006)
Yield (kg ha-1)
600
400
200
0
NxP
(+)
N
N
Unsignificant
P effect
N0–P0
N0–P10
N22–P0
N22–P10
Treatment (kg ha−1)
Serial P (LM) : Winter wheat
(Takahashi and Anwar 2006)
Yield (kg ha-1)
4000
3000
2000
1000
0
NxP
(+)
P
P
N0–P0
N0–P30
N100–P0
N100–P30
Treatment (kg ha−1)
Independent Super-additive (Low Input) - Independent Sub-Additive (High Input) (MLH) : Faba bean
(Adak and Kibritici 2006)
Yield (kg ha-1)
Low input
High input
1000
500
0
NxP
(+)
N
P
N
P
N
P
N
NxP
(-)
P
N0–P0
N0–P18
N30–P0
N30–P18
N0–P35
N60–P0
N60–P35
Treatment (kg ha−1)

Fig. 5

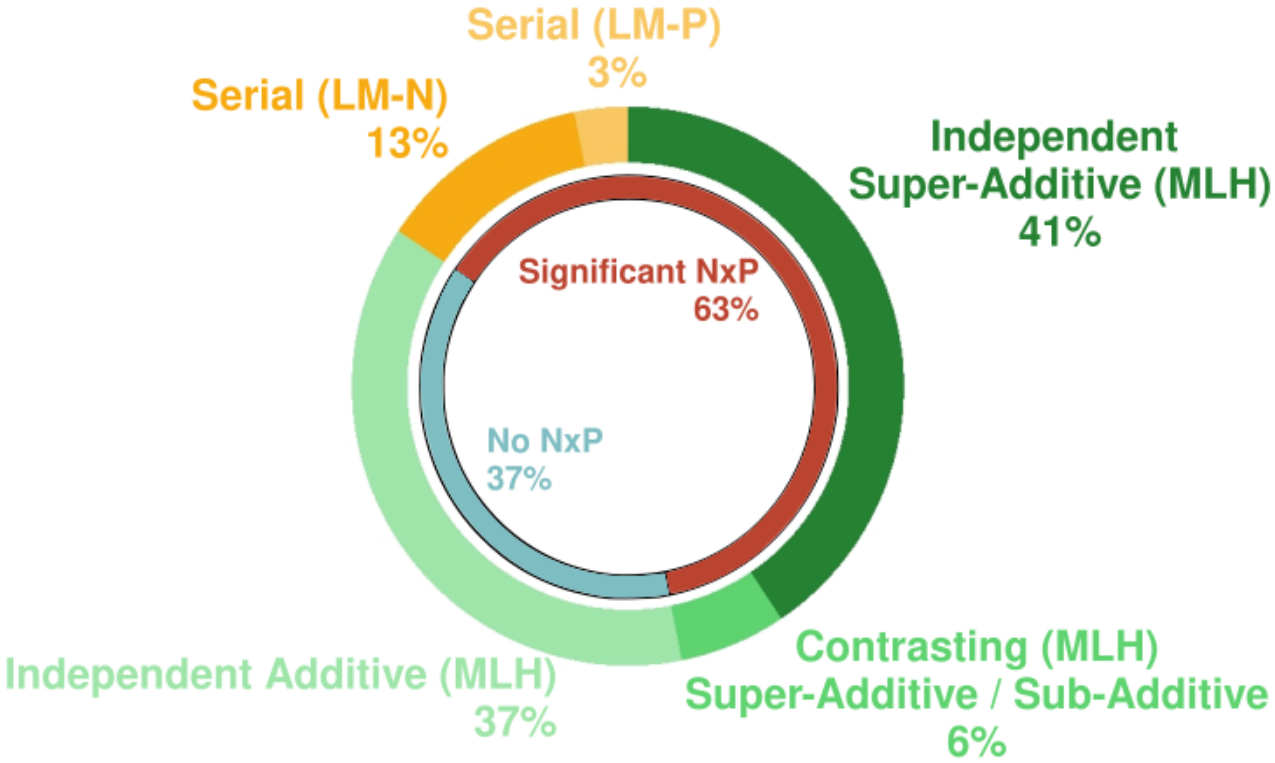

Serial (LM-P)
3%
Serial (LM-N)
13%
Independent
Super-Additive (MLH)
41%
Significant NxP
63%
No NxP
37%
Independent Additive (MLH)
37%
Contrasting (MLH)
Super-Additive / Sub-Additive
6%

Fig.6.

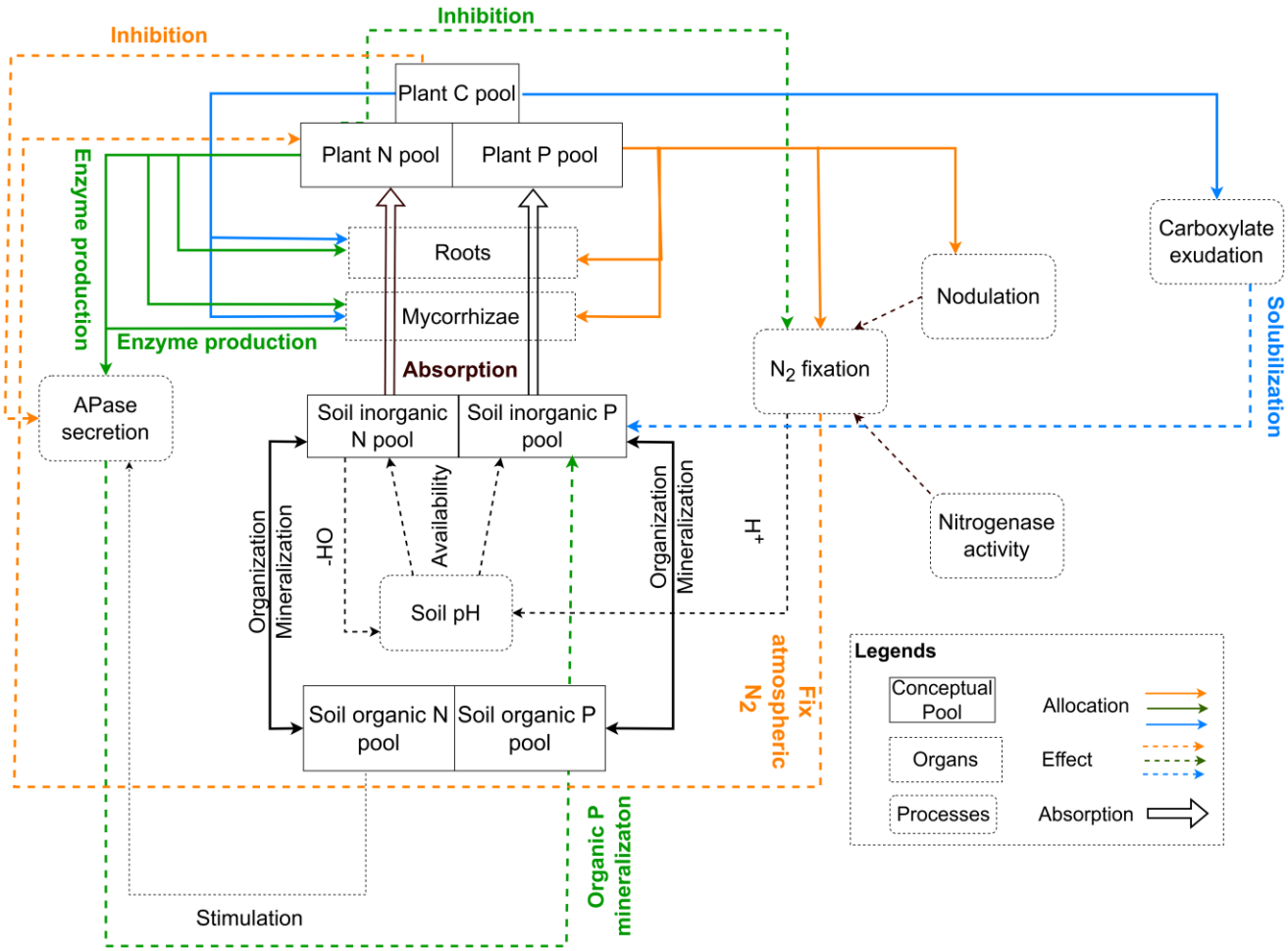

Inhibition
Inhibition
Plant C pool
Plant N pool
Plant P pool
Enzyme production
Enzyme production
Roots
Mycorrhizae
Absorption
Carboxylate exudation
Nodulation
Solubilization
N2 fixation
APase secretion
Soil inorganic N pool
Soil inorganic P pool
Organization Mineralization
-HO
Availability
Organization Mineralization
+H
Nitrogenase activity
Soil pH
Legends
Conceptual Pool
Allocation
Organs
Effect
Processes
Absorption
Soil organic N pool
Soil organic P pool
Fix atmospheric N2
Organic P mineralizaton
Stimulation

Fig. 7.